National Aeronautics and Space Administration

Overview of Initial Development of Flexible Ablators for Hypersonic Inflatable Aerodynamic Decelerators

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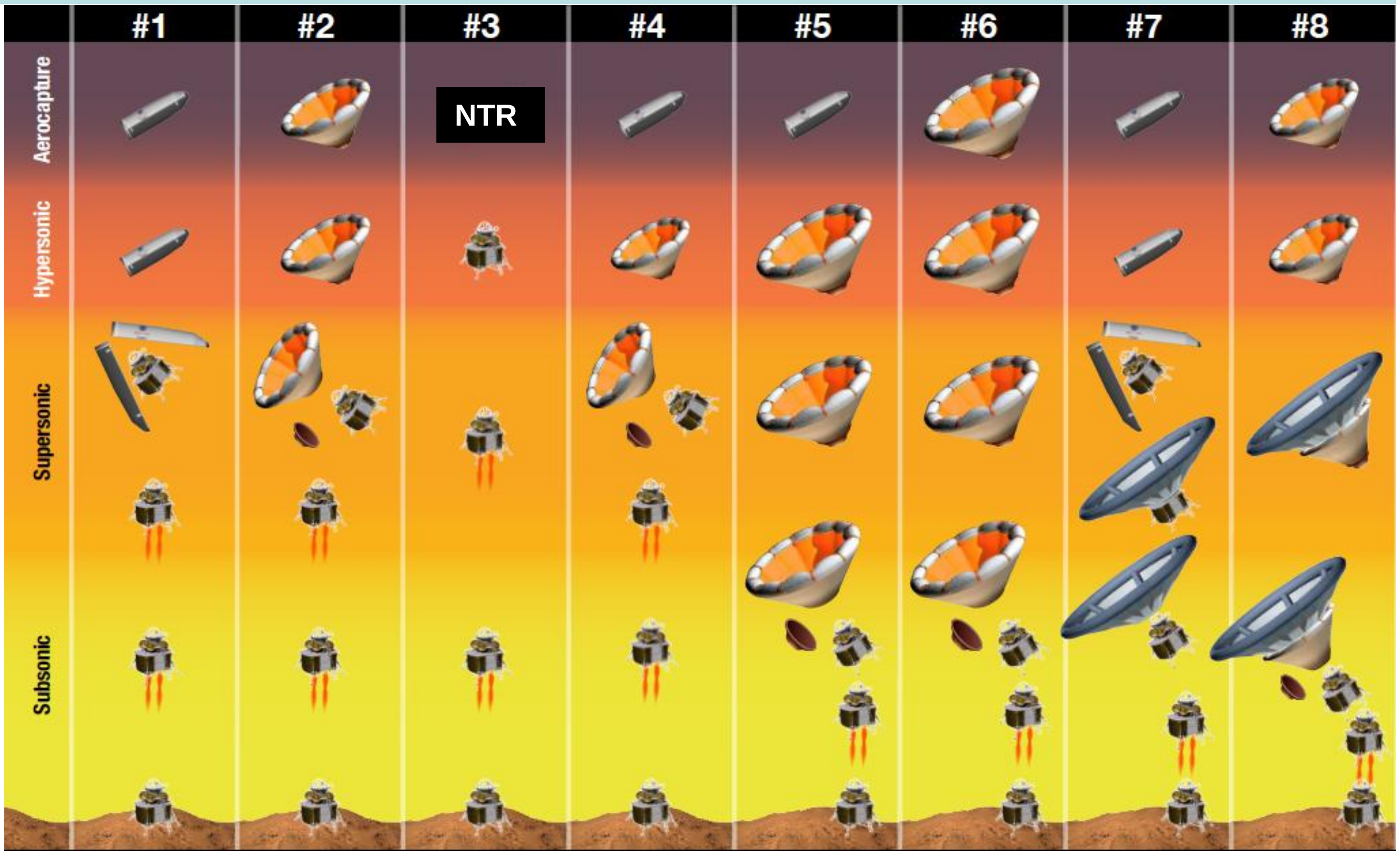
Motivation

- NASA's desire to land larger payloads on Mars (10s of metric tons) has renewed interest in alternative technologies for entry, descent, and landing (EDL)
- Significant improvements needed beyond MSL (~1 mt landed):
  - Order of magnitude increase in payload mass (10s of metric tons)
  - Four orders of magnitude improvement in landing accuracy (meters)
  - Higher landing elevation
- **NASA systems analysis (EDL-SA) study recommended development of new technologies:**
  - Deployable or inflatable aerodynamic decelerators for aerocapture and/or hypersonic entry at sizes requiring development of flexible ablative materials
  - New rigid aeroshell shapes that improve lift-to-drag ratio (L/D) requiring new innovative, lighter-weight rigid ablative material systems
  - Propulsive deceleration initiated at supersonic conditions = Supersonic Retro-Propulsion (SRP)

EDL Year 1 Systems Analysis Architectures

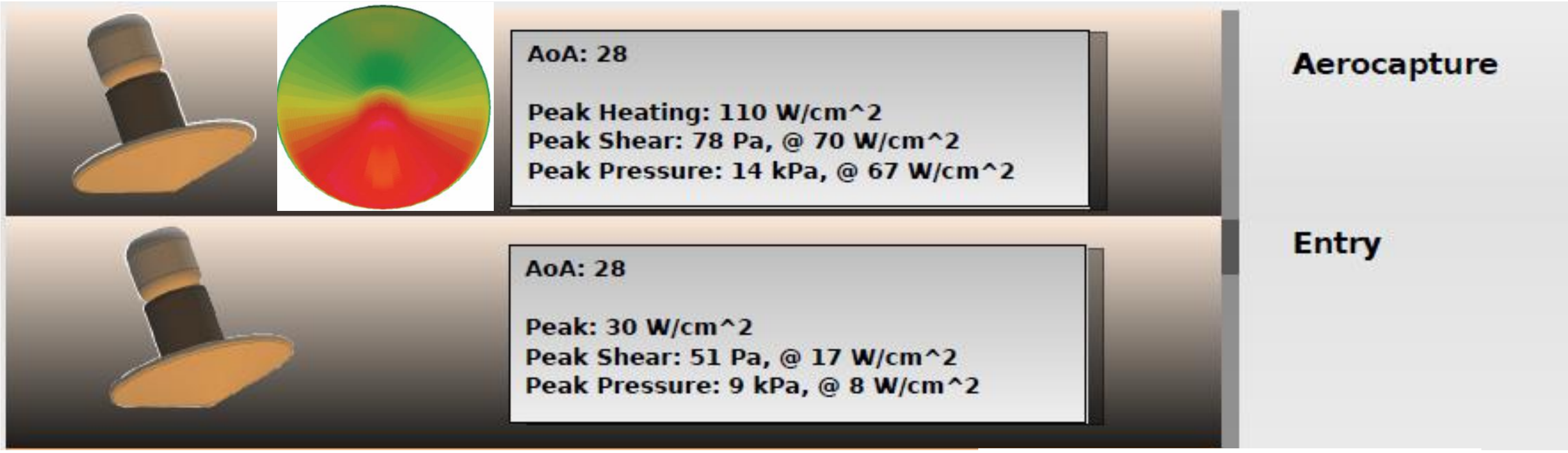
- Recent studies of high-mass (40 mT payload) Mars entry systems require flexible ablative materials as an integral part of candidate EDL architectures

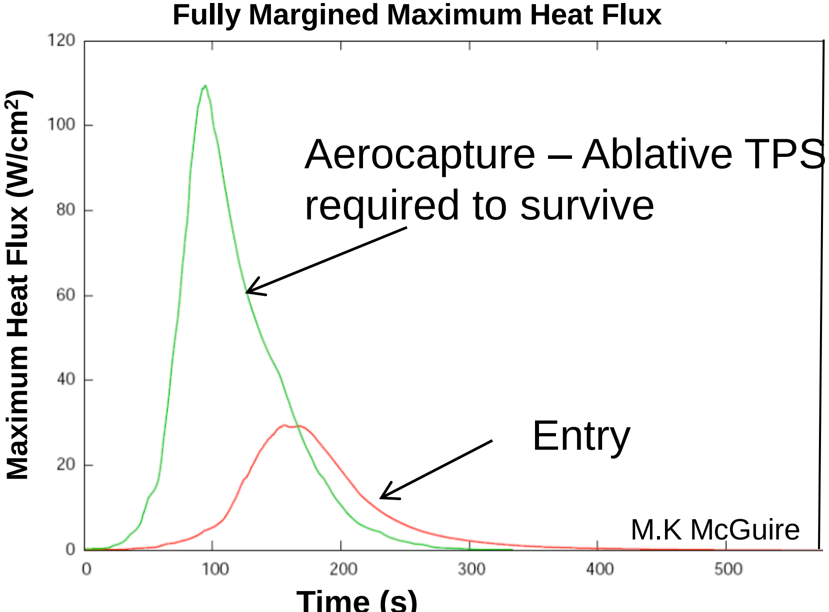
Entry Mass	110	84	265	109	134	141	107	81

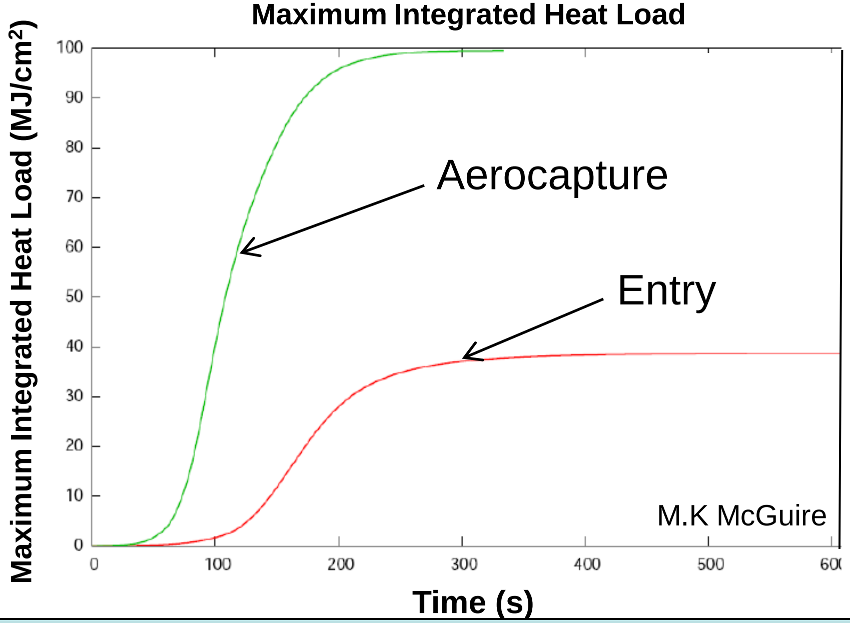


Zang, et al, "Entry, Descent and Landing Systems Analysis Study: Phase 1 Report"

Deployable 23-m Diameter Heatshield Heating Environments



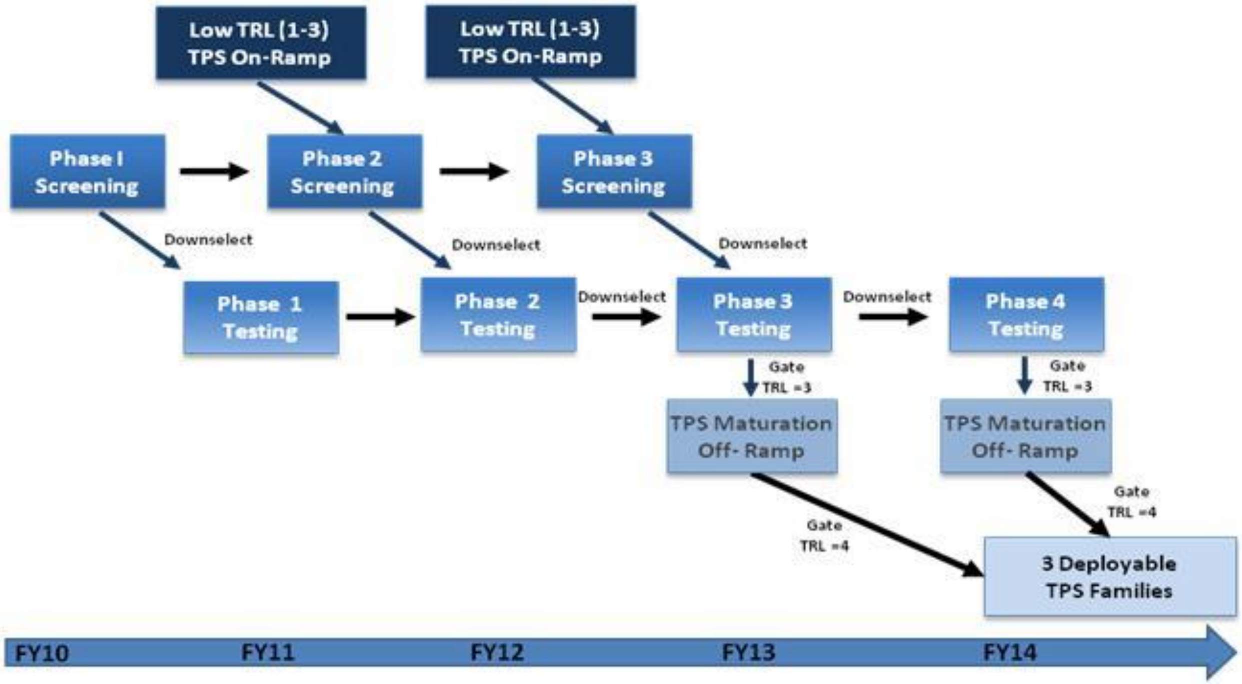




EDL HIAD scenarios 2 and 8 require flexible ablators capable of withstanding two heating pulses

Flexible Ablator Technology Development Approach

- FY10:
  - Develop evaluation criteria to describe successful development, define key performance parameters
  - Develop and/or procure first attempts at flexible ablators (10 NASA, 2 vendor)
  - Perform thermal and structural screening tests
  - Downselect “best” concepts for further maturation
  - Plan for FY11 material concepts for Phase 2 screening (on-ramp of new matl’s)

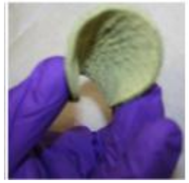


NASA Flexible Ablator Development

- Leverage NASA experience with the invention/development of ***rigid*** heatshield materials
  - SIRCA (Silicone Impregnated Reusable Ceramic Ablator)
  - PICA (Phenolic Impregnated Carbon Ablator)

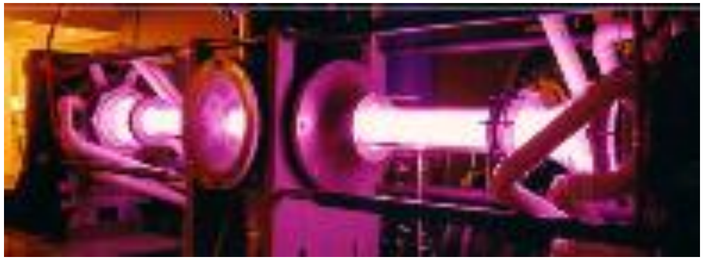
SIRCA cousin

PICA cousin



- Utilize flexible matrixes
  - Silica-based and carbon-based felts or cloths
  - Polymer-based felts
  - Organic/inorganic blended materials
- Experiment with resins, catalysts, and solvents to result in flexible composites
- Perform a series of screening tests to determine viability of the concepts
  - Aerothermal screening in NASA Ames X-jet plasma torch
  - Thermal screening in radiant environment at the Laser Hardened Materials Evaluation Laboratory (LHMEL) including dual heat pulse evaluation
  - Aerothermal screening in NASA Johnson Space Center Atmospheric Reentry Material and Structures Effects Facility (ARMSEF) Test Position 2 (TP2) arc heater
  - Fold testing for stowability effects
  - Transmission testing to evaluate susceptibility to Near-Infrared radiation in CO_2 shock layer
- Develop low fidelity (scaled) response models to compare with data
- Evaluate materials

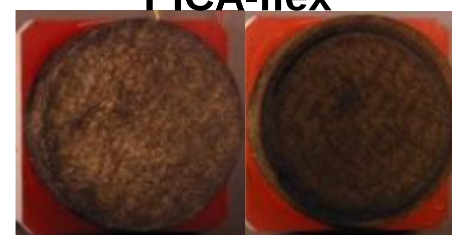
Screening Tests: Thermal



Wright Patterson AFB
LHMEL I facility

SIRCA-flex

PICA-flex



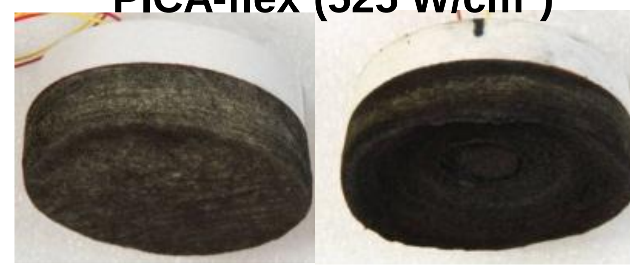
- LHMEL I 10kW CO_2 laser (10.6μm) used to compare material thermal response when exposed to radiant energy in inert N_2 environment
  - In-depth response indicative of thermal protection capability
  - High test rate allows for testing many specimens
  - Surface temperatures and interface temperatures were recorded
- Three specimens of each material were exposed to 115 W/cm^2 to simulate aerocapture
- One specimen of each material was then tested at a second exposure of 30 W/cm^2 to simulate entry to evaluate the effects of a the *dual heat pulse requirement*
- PICA cousins were also tested to higher heat rate 450 W/cm^2 to establish capability
- One sample of each material was exposed to 115 W/cm^2 in the 10kW IPG Photonics Fiber Laser (1.07μm)
  - Evaluate in-depth absorption of shorter wavelength (CO_2 shock layer wavelengths)
  - Compare to CO_2 (10.6μm) laser results - absorption seen at 1.07 μm on silica-based materials

Screening Tests – Aerothermal

NASA Johnson Space Center ARMSEF TP2 facility

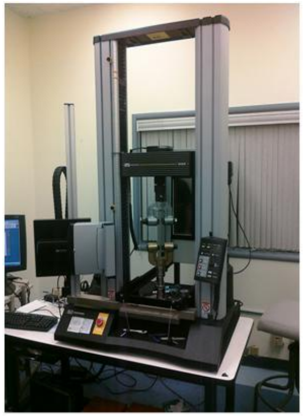
SIRCA-flex (125 W/cm^2)

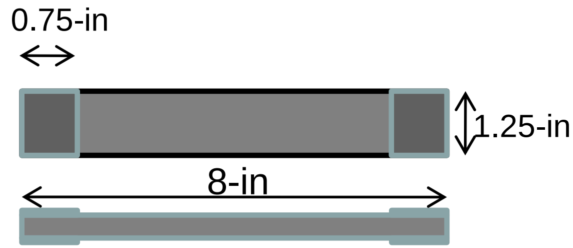
PICA-flex (525 W/cm^2)

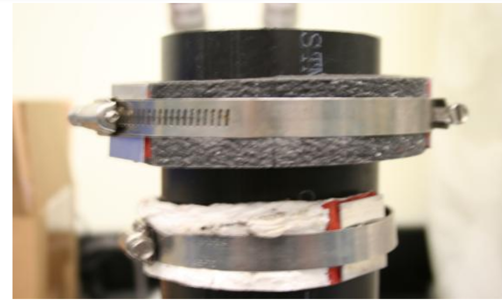


- The objective of this test program was to obtain ablation and thermal performance data
- Performed initial screening and gathered input to first order thermal response models
- The materials tested during this series were a subset of those tested in LHMEL
- Most materials performed well in Mars EDL HIAD heat flux conditions (125-150 W/cm^2 coldwall and 15 kPA)
- PICA cousins were tested at higher (Mars EDL rigid aeroshell) conditions (525 W/cm^2 coldwall and 35 kPA) and performed well
  - Application of PICA cousins on rigid aeroshells would eliminate tile and gap filler issues experienced by PICA

Screening Tests – Fold Tests







- Tension test – Evaluate stiffness and in-plane tensile strength
- Fold Test – Evaluate foldability of the materials for a given radius of curvature of 3.25 in (derived based on KPP of ~6” diam)
- Some materials showed residual stresses due to folding

Visual Inspection and high resolution photo to record, flaws, preexisting damage etc.

→ Uniaxial tension test (in elastic zone)

→ 1. Record and compare data with Tension only coupons
2. Visual Inspection

→ Fold test on 6.0in diameter PVC Pipe (2 weeks)

→ 1. Investigate Foldability
2. Visual Inspection and high resolution photo to record, flaws, damage due to fold,
3. Inspect surface under microscope

→ Uniaxial tension test (in elastic – plastic zone)

→ 1. Record and compare data with Tension only Control coupons
2. Visual Inspection

Evaluation Criteria

- Evaluation criteria were established in order to compare materials in initial trade studies to downselect for further maturation
  - Thermal performance
  - Structural performance
  - Complexity of materials response model development
  - Robustness
  - Tailor-ability to different missions
- Additional criteria will eventually be used for decisions on full scale materials development
  - Reliability
  - Manufacturing repeatability
  - Development cost/schedule risk
  - Qualification cost/schedule risk
  - High fidelity thermal response model development and validation cost and schedule risk
  - High fidelity thermostructural model development and validation cost and schedule risk
  - Cost/schedule risk for full scale manufacturing
  - Life cycle costs
  - Supplier viability

FY11 Work

- Further evaluation of FY10 trade studies led to the conclusion that the “best” FY10 materials warranted further development rather than maturation as envisioned in original approach (slide 5)
- NASA has been making new, improved variants on the FY10 materials (~15 new materials)
  - Felts, resins, catalysts, solvents, additives, and coatings all evaluated for possible material improvements
- Industry proved more willing to participate in FY11 with 5 materials chosen for screening
- Screening will be performed using the same approach as FY10
  - Thermal Screening in LHMEL
  - Aerothermal Screening in ARMSEF TP2
  - Structural Screening (fold tests)
  - Shock layer radiation transmission tests
- Screening in a simulated Mars CO2 aerothermal environment has been added to the test plans for FY11
  - Hypersonic Materials Environmental Test System (HyMETS) facility at NASA Langley Research Center

Summary and Conclusions

- NASA's EDL systems analysis study recommended the development of flexible ablative materials for use on deployable aerodynamic decelerators
- NASA developed a first round of flexible ablators that were screened in thermal, aerothermal, and structural environments
- Many of the materials showed promise in survivability at the Mars HIAD EDL conditions
- Some materials showed promise at much higher conditions: Flexible ablators showed promise as a replacement for traditional rigid ablators
- NASA is continuing to innovate and improve flexible ablative material concepts

Feasibility of flexible ablator technology demonstrated

Acknowledgements

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- For accompanying paper, see AIAA-2011-2511